# POTABLE WATER

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"*He who learns the rules of wisdom without conforming to them in his life, is like a man who labored in his fields but did not sow.*"—Saadi.

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# POTABLE WATER.

## I. PURE WATER.

Water is a chemical compound of hydrogen and oxygen, which is widely diffused in nature. As a solid, it exists as snow and ice; as a liquid, it constitutes streams, lakes and seas, and in a state of minute subdivision, mist and clouds; while as a colorless gas, it is always a constituent of the air. Natural waters are always impregnated with certain foreign constituents which give to them their varying properties; and in the examination of water for sanitary purposes, it is not the water which is analyzed, but its impurities.

The palatability of water depends upon its occluded gases, which are principally oxygen, nitrogen, carbonic anhydride and hydrogen sulphide. These gases are readily absorbed, and they give to the water an agreeable taste, and a sparkling brilliancy. The high degree of palatability of spring-water is mainly due to its carbonic anhydride. Distilled water, or water deprived of its gases by boiling, is insipid or "flat;" but by aeration and acidification it regains its palatability. Water must be more or less impregnated with gases before it is even suitable to the dietetic needs of man; for when water deprived of its gases, is used for purposes of experiment, it is found to be prejudicial to health, as the stomach cannot gratefully receive and advantageously appropriate it. (1)

Researches in etiology have shown that the health of an individual, or of a community, depends largely upon the purity of the water supply. It is not chemically pure water, however, that is needed for the maintenance of perfect health, for such water does not exist in nature. As chemically pure water contains nothing injurious to the system, it likewise contains nothing beneficial, and for healthy persons, such water is not the most wholesome. The

(1) Van Nostrand's Engineering Magazine, December, 1872, p. 593.

healthy human system ordinarily requires mild cathartics and other mineral salts for the continuity of health. These, in part, can be best furnished to the system as the mineral constituents of potable water. The wholesomeness of water is therefore increased by the presence of small quantities of certain mineral salts, in solution, which act as laxatives, and which are essential to the development of animal tissue; but drinking water should be free from organic impurities. As a rule, chemists condemn all waters which are contaminated with sewage, such contamination being shown by chemical and microscopical analyses, and by an examination of the sources of supply. From a sanitary standpoint, pure water may be defined as water which is unobjectionable for general domestic use, and especially that which may be used with perfect safety for drinking purposes.

Some waters are so unpotable that the appetite does not demand the amount required for the normal functions of the body. Such waters not only lessen bodily vigor and frequently produce disease, but an insufficient supply of any water is manifested by great pain, relaxation of muscular strength and of mental vigor, and diminution in the elimination of pulmonary carbonic anhydride and bodily excretions. So, when we consider that about seventy(2) per cent of the human body is composed of water, which is being constantly eliminated, the need of maintaining a copious supply of pure water becomes apparent; but an abundance of water is no more necessary to the support of life than its purity is to the continuity of health. People may habitually drink impure water and still live, but its use unquestionably affects the human system and tends to the degeneration of a race. Experience shows that even slightly impure water may be productive of a host of ailments for which the sufferer finds no apparent cause; for the results are often so slow and gradual as to evade ordinary observation, and the evil is borne with the indifference and apathy of custom. It is only when striking and violent effects are produced that public attention is arrested.

A water which is constantly used for domestic purposes should have the following qualities:

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(2) Human Physiology, Dalton, Seventh Edition, p. 36.

1. It should be free from odor and taste.

2. It should be free from dead vegetable and animal organisms, and should contain only such living forms as are purifying agents.

3. It should at all seasons of the year be well aerated, uniform in temperature, and free from suspended matter.

4. It should contain only a small quantity of mineral matter in solution, and be free from all the poisonous salts.

For persons afflicted with renal diseases, distilled water in its crystalline purity is probably the most healthy beverage, for it acts upon the kidneys as a powerful therapeutic agent in the solution and removal of the waste products of the body. Upon this point Professor Charles Mayr(3) says: "Those who have never drunk pure water do not realize what an effect such water has upon the kidneys; its effect is better than that of acetates, nitrates, opiates or alcohol, and for people with tendency to kidney diseases or Dropsy there is no better drug than pure water. Of the thousands of chemical compounds and waste products found in the human system, many require pure water for their solution and elimination; and water so overloaded with salts as average well-water will not work satisfactorily."

## II. INORGANIC IMPURITIES.

Water is the most nearly universal solvent in nature, and as it passes into the earth, charged with atmospheric gases, it dissolves many salts. When it reappears again on the surface in springs, and flows away in streams, it is often heavy laden with mineral constituents; but the streams and lakes in granite regions are very nearly pure. The oceans and inland seas are the final reservoirs of flowing water, and they become saline from the concentration of their mineral matter, through evaporation. Sea water contains about two thousand grains of total solids per gallon, while the waters of the Great Salt Lake and the Dead Sea each contain about twelve thousand grains. (4)

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(3) Report of New Jersey State Board of Health, 1887, p. 338.

(4) Manual of Mineralogy and Petrography, Dana, p. 252.

From an examination of the water supplies of sixty-five English and Scotch cities and towns, Dr. H. Letherby,(5) an eminent English chemist and sanitarian, concluded that the rate of mortality was inversely as the amount of mineral salts in the water supplies.

Only certain constituents, however, are beneficial to health; others are deleterious; and a water which contains too large an amount of mineral salts should be avoided, as it is liable to produce derangements in the alimentary canal.

When the amount of mineral constituents in water becomes so excessive as to give it decided medicinal properties, the water is styled mineral or abnormal. Many salts have a characteristic taste, and the nature of mineral waters can, therefore, often be determined by the sense of taste alone. Mineral waters are classified according to the principal substance in solution. Thus a chalybeate water has in solution an excess of an iron salt, usually carbonate or sulphate, and which, upon standing exposed to the air, generally deposits a yellow precipitate of carbonate of iron; a saline water has in solution an excess of some salt, like sodium chloride, or sodium and magnesium sulphate; a carbonated, effervescent or acidulous water has carbonic anhydride in excess; while a sulphur or hepatic water contains an excess of hydrogen sulphide. Upon standing, hepatic waters become somewhat turbid and deposit sulphur.

Saline waters, when used occasionally and moderately, are beneficial to health, owing, in part, to the cathartic action of the sulphates and phosphates of the alkalies and alkaline-earths, which are usually found in such waters; but their excessive use, or the prolonged use of waters containing too much salts in solution, should be avoided. Saline waters often afford relief to persons afflicted with Inflammatory Rheumatism, when they are frequently used for bathing purposes. Carbonated waters are not only highly palatable, but they are very beneficial to persons suffering from Dyspepsia. But waters containing much hydrogen sulphide are

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(5) Report of Michigan State Board of Health, 1876, p. 78.

not really wholesome, as they will produce Diarrhea,(6) especially if organic matter be present; but in small quantity hydrogen suphide is not in any way injurious to health.

Some salts are productive of Indigestion, and in many cases Constipation and visceral obstruction are induced by the use of mineral waters. Chalybeate waters not unfrequently induce in the drinker, Headache, Indigestion and Dyspepsia. A drinking water should not contain more than one fifth(7) of a grain of iron per gallon. Calcium and magnesium chlorides and sulphates will produce Chronic Diarrhea, and if the water also contains ammonium and calcium nitrates and sodium chloride in excess, and is used freely, it is sometimes the cause of Dysentery. Dyspepsia is also frequently produced by water containing calcium and magnesium salts. Goitre, so frequently found among the inhabitants of some of the valleys of Switzerland, is caused by the excessive permanent hardening constituents of the water. A water containing not more than seven(8) grains of salts per gallon is said to be injurious to many persons. "With regard to the total quantity of impurities admissible in good drinking water, the Sanitary Congress which met at Brussels decided that water containing more than thirty-five grains of impurity in one gallon is not wholesome, and that there should not be much more than one grain of organic matter."(9)

The normal carbonates of the alkaline-earths, magnesium and iron, are practically insoluble in pure water.(10) But the bicarbonates of these metals, which are readily soluble, are formed by the union of carbonic anhydride and water, with the normal carbonates, and there is scarcely a natural water which does not contain a small amount of them. It is claimed by some eminent authorities that small quantities of these bicarbonates in drinking water are beneficial to health; but experience has also shown that large quantities

(6) Practical Hygiene, Parkes, Seventh Edition, p. 58.

(7) Water Analysis, Wanklyn and Chapman, Sixth Edition, p. 61.

(8) Practical Hygiene, Parkes, Seventh Edition, p. 56.

(9) Report of American Public Health Association, Vol. I, p. 538.

(10) "About one grain of calcium carbonate to the gallon is usually stated to be the proportion dissolved, but it has been pointed out lately by Allen, that this is an understatement, since solutions have been obtained containing twice this amount."—[Examination of Water for Sanitary and Technical Purposes, Leffmann and Beam, p. 93.]

of these salts are sometimes injurious. If in excess, they are decomposed in passing through the system, and give rise to renal and bladder difficulties, which often culminate in Gravel. The bicarbonates are not generally found in well-waters in excessive or dangerous quantities; but the continued use of spring-water which flows from limestone rock will eventually give rise to disease, for communities which use only limestone water are generally afflicted with diseases which arise from overworked kidneys. These bicarbonates are the constituents of temporary hardness in water, and they can be removed by boiling, as by this operation bicarbonates are decomposed into normal carbonates, which precipitate, and carbonic anhydride and water which escape. Water is usually rendered permanently "hard" by the solution of the sulphates of calcium, magnesium and iron.

The salts of some elements, like arsenic, antimony, barium, chromium, zinc, copper and lead, are dangerous poisons, and water containing even traces of them should always be avoided. Lead poisoning is not unfrequent in some cities where the water for domestic use passes through lead pipes. Aerated water tends to dissolve lead, forming a hydrate, which in presence of carbonic anhydride in excess, forms a slightly soluble bicarbonate of lead. Chlorides and nitrates in water also tend to form insoluble compounds on the inner surface of the pipes, which prevent further action of the oxygen upon the lead. Lead pipes should, therefore, only be used in conveying drinking water, which contains an excess of sulphates or normal carbonates in solution. Indeed, it is doubtful whether lead pipes should be used at all for a water supply, as a water which contains a sufficient quantity of the necessary salts to prevent the solution of lead, is liable to produce derangements in the alimentary canal.

Potable water often contains suspended mineral matter, such as sand and clay, and it is believed that an excessive turbidity caused by these, is productive of intestinal difficulties, Indigestion, Dyspepsia and Diarrhea. The character of the suspended matter can only be fully determined by means of the microscope.

## III. VEGETABLE IMPURITIES.

The turbidity of water is sometimes produced by decomposing organic matter, which is, with the exception of pathogenic germs, the most deleterious of all impurities.

Although the products of vegetable decay indirectly produce malarious diseases, they are not in themselves especially injurious to the human system; they merely furnish a pabulum in which certain disease germs flourish, for the malarious influence is attributed by medical science to micro-organisms. These living germs are most frequently conveyed to the system in the air, but the most dangerous types of malaria are caused by polluted water, which seems to be a more concentrated and dangerous poison than malarious air. And in the production of remittent fever(11) by malarious surface-water, it is noticeable that the disease is always of a more aggravated type than when caused by exhalations from miasmatic soil. So, water which shows by analysis that it contains decomposing vegetable matter, should always be avoided.

By the drainage of swamps and the cultivation of the soil, communities have often freed themselves of much sickness of a dangerous, malarious character. Decaying wood, like pump-stocks and storage-tanks, often produce harmful results, through the water, and the decomposition of sawdust(12) in water is a fruitful source of all forms of malarious fever.

Many cases are on record from the American Civil War, in which the use of surface-water, impregnated with the debris of plants, like cellular tissue and chlorophyl, also produced Diarrhea; but when such water was filtered the disease abated.(13) The water supplies of some of the eastern cities have at times a decidedly fish-like odor, which Professor Lattimore has shown to be due to the presence of *Algæ*, perhaps in a state of decomposition. The little filaments of decomposing *Algæ*, when seen under the microscope, are usually changed in color and broken down in structure. It is

(11) Water Supply of U. S. Capitol, 49th Congress, 1st Session, Ex. Doc. No. 154, pp. 8-9.
(12) Report of Michigan State Board of Health, 1882, p. 155.
(13) Practical Hygiene, Parkes, Seventh Edition, p. 57.

the opinion of the most competent judges that waters containing such filaments, if used for a considerable length of time, are very injurious to health; and certain *Algæ* in a water supply are sometimes accompanied by an alarming mortality of fish.[14] Pond water, in which there is a copious growth of aquatic plants, is said to produce intestinal worms.

Recent investigations[15] have shown that many varieties of *Algæ* are probably capable of producing an objectionable taste and odor in water, which, in case of the grass-green varieties, are especially rancid; but power to produce these changes is entirely independent of color. *Nostoc*, a greenish, gelatinous, translucent variety of *Algæ*, which develops rapidly in wet places after a rain, is a frequent source of contamination of water; and it is of especial interest in this connection as being the chief source of the unpleasant "pig-pen" odor of water. The intensity of the physical exponents, taste and odor, may be taken as a measure of the rapidity of decomposition of the *Algæ* present in water at any given time, and they are consequently a measure of its cryptogamic pollution.

But there are certain living *Algæ* that may be taken as a measure of the organic pollution of water. Thus, the *Flagillata* are generally found in water containing decaying infusions of vegetable and animal matter, and they have been detected in the dejections from Cholera and Typhoid Fever patients. The *Beggiatoa alba*, a species of *Algæ* closely resembling some forms of *Bacteria*, is also only found in stagnant waters, and it is, therefore, indicative of harmful pollution.

Some waters which come from clay soil have so strong an odor of hydrogen sulphide and sulphuretted hydro-carbons as to be undrinkable, and yet the organic matter in them will not often warrant their condemnation. These gases are probably produced in the decomposition and reduction of sulphates, by decomposing organic matter, and by living *Bacteria* and low forms of *Algæ*. According to Professor Nichols,[16] decaying organic matter, in water, under

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(14) On the Micro-Organisms in Hemlock Water, Rafter, p. 16.

(15) On the Fresh Water Algæ, and Their Relation to the Purity of Public Water Supplies, Rafter, p. 2.

(16) On the Fresh Water Algæ, and Their Relation to the Purity of Public Water Supplies, Rafter, p. 10.

favorable conditions of temperature, reduces sulphates to sulphides, and from these, hydrogen sulphide is liberated by the acid products of decay.

The genus *Beggiatoa* only exist in water containing some form of sulphur, when free from iron. (17) These organisms probably possess the power of extracting sulphur from decomposing organic matter containing it, with the liberation of hydrogen sulphide. They also possess the power of extracting sulphur from sulphates in water, appropriating the sulphur in an amorphous state into the protoplasmic mass of their cell structure, with the liberation of the balance of the sulphur as hydrogen sulphide. The presence of hydrogen sulphide in a water supply is, therefore, no reliable indication of organic pollution.

Pure water in thin layers is almost colorless, but in considerable volume it has a decidedly bluish tint, which comes from its power to absorb, reflect, and transmit white light. Rain-water is some times highly colored with vegetable matter from the roofs of buildings, but it is often the healthiest of drinking water, on account of the stability of its organic matter. The chlorophyl of unicellular *Algæ*, growing in water, often colors the water green. Peat gives to water a brownish color, but analyses and long continued use demonstrate that such water is usually wholesome. It is true that such water has sometimes a laxative effect upon the system, but its action is only temporary, and so can in no sense be injurious. Peat water is often used for drinking purposes on long ocean voyages, on account of its power of retaining freshness.

### IV. ANIMAL IMPURITIES.

The products of decomposition of animal matter are always more dangerous to the human system than those from vegetation, as some of them are highly nitrogenous; and water which is contaminated with the animal accumulations of sewers, cess-pools, and privies, is a most loathsome and dangerous poison. A microscopic examination of polluted water often reveals the presence of hair, excreta, intestinal epithelial cells, and living organisms. Such water should

(17) Water Analysis, McDonald, p. 25.

be absolutely condemned for all sanitary purposes, as the impurities could only come from sewers and privy-vaults, and the living organisms feast upon the products of decay.

Animal matter is highly putrescible, and water containing it is liable to produce putrefactive changes in persons drinking it. The nitrogenous matter decomposes by oxidation and disintegration, through the agency of micro-organisms, producing in its earlier stages, *Ptomaines*, bodies which are closely allied to the vegetable alkaloids, but more susceptible of decomposition. Although the *Ptomaines* are present in very small quantity in polluted water, yet they are very active in their physiological effects, and produce harmful results when taken into the system. Other products of decomposition furnish a suitable pabulum for the accumulation and multiplication of germs of disease. Many contagious and infectious zymotic diseases are produced by water polluted with decomposing animal matter, and indeed, it is highly probable that certain diseases are seldom produced in any other way. (18) Polluted waters are often deceptive, since they generally have an agreeable taste and are highly palatable.

In the Fall of 1887, Typhoid Fever became epidemic in Ottawa, Minneapolis, Pittsburgh, and many other cities, and it was found on examination that in every case known to the writer, the disease was communicated through potable water. In Pittsburgh the circumstances were especially interesting. The south side of the city was supplied by the Monongahela Water Co.'s works, and the fever was located in districts supplied by that company. Upon chemical and microscopical examination of the water, the pollution was traced many miles above the city to a ravine into which drained the privies of houses where four Typhoid Fever patients had been located several weeks before. (19)

From 1856 to 1866 there were twenty-one thousand deaths from

(18) "There is abundant proof that drinking water has been instrumental in the spread of the following diseases: Cholera, Typhoid Fever, Dysentery, Diarrhea Diphtheria, Malaria, Cholera Infantum, and Cerebro-spinal Meningitis; and in addition to these, certain low forms of fever to which no other name than Continued Fever can be given."—[Report of Brooklyn Commissioner of Health, March 10, 1884, p. 19.]

(19) Report of Special Committee on South Side Water Supply, Pittsburgh, December 23d, 1887.

Cholera, and one hundred and fifty thousand deaths from Typhoid Fever, in England and Wales;([20]) while now in all of Great Britain twenty thousand persons die and two hundred thousand suffer annually from Typhoid Fever, and the majority of cases are produced by polluted water. ([21])

In Michigan the annual mortality from Typhoid Fever is about one thousand, while ten thousand persons are annually afflicted with this disease. ([22])

In the United States thirty thousand people die annually from this fever alone. The mortality from Typhoid Fever in many of the eastern cities is proportional to the quantity of sewage which enters the water supplies. ([23]) The annual death rate from this disease per one hundred thousand inhabitants in Brooklyn is about fifteen, in New York city twenty-five, and in Boston forty; while in the city of Vienna, from 1851 to 1874, while impure well-water and a supply from the Danube were used, the annual death-rate was from one hundred to three hundred and forty per one hundred thousand inhabitants. By the use of spring-water in place of the former supplies, the mortality from Typhoid Fever, in Vienna, has been greatly reduced. During the last three years the annual death-rate in that city has only reached eleven per one hundred thousand inhabitants.

Some of the lowly-organized animal scavengers, which assimilate the decomposition products of organic matter, are injurious to the human system, but the majority of them are harmless, and nearly all of them are purifying agents.

Polluted water is generally infested with *Infusoria*. ([24]) This is especially true of stagnant surface-water, and the water from many surface wells. Recent investigations in biology demonstrate that nitrogenous food is necessary for the development of such life in water; but there are certain conditions not yet clearly understood,

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([20]) Report of Brooklyn Commissioner of Health, March 10, 1884, p. 78.

([21]) Report of Michigan State Board of Health, 1884, p. 116.

([22]) Report of Michigan Sanitary Convention, December 6 and 7, 1887, p. 24.

([23]) Report of Committee on the Pollution of Water Supplies, American Public Health Association, 1888, p. 5.

([24]) "The Animal World of Well-waters," Popular Science Monthly, June, 1889, pp. 251-257.

favoring the transformation of harmless organic matter, in presence of nitrogen salts and phosphates, into a favorable pabulum for the growth of micro-organisms.[25] Phosphates are not usually found in potable water, and the presence of infusorial life in water free from phosphates, is, therefore, very reliable evidence of its pollution.

The ciliated embryos of certain *Entozoa* are sometimes found in potable water. They are generally very active in early life, but finally lose their ciliated covering and perish, unless they find their way into the body of some animal drinking the water.

*Cyclops*, or water flea, is one of the most common genera of *Entomonstraca* found in potable water. Dr. H. C. Sorby[26] has shown that the number of certain of the *Entomostraca* in water may be taken as a measure of its organic pollution, for an increase in sewage is indicated by an increase in their total number, or by an alteration in the relative number of each species, or by both. It is not known whether *Infusoria*, *Entomostraca*, and certain forms of microscopical animal life are the agents or the companions of disease, but serious outbreaks of Fever, Diarrhea, and Dysentery have been produced by water swarming with these forms of life.[27]

*Leeches* are sometimes accidentally swallowed in potable water. They are liable to attach themselves on the pharynx, and when once fixed they seldom fall off spontaneously. Coughing, nausea, and spitting of blood are produced by them, and repeated bleeding from the larynx produces anæmia.[28]

## V. BACTERIA IN WATER.

Living germs are even more dangerous in drinking water than animal organisms and dead organic matter. Some diseases, such as Cholera, Typhoid Fever and Diphtheria, are generally believed to be produced by micro-organisms, which, like the spores of some plants, are thrown off with the excretions of persons suffering with

(25) On The Micro-Organisms in Hemlock Water, Rafter, p. 4.

(26) On the Micro-Organisms in Hemlock Water, Rafter, p. 25.

(27) On the Use of the Microscope in Determining the Sanitary Value of Potable Water, Rafter, p. 11.

(28) Practical Hygiene, Parkes, Seventh Edition, p. 78.

the disease, and they find their way mainly through the water supply, to those who, from predisposing causes, are in a suitable condition for the reception and multiplication of the germs and the production of the specific form of disease. These pathogenic micro-organisms are known as *Bacteria*, and the diseases which they produce, zymotic, in consequence of their course resembling a process of fermentation; but only few *Bacteria* are pathogenic. The most common forms of these organisms are not more than one fifteen thousandth or one twenty thousandth of an inch in length, and it has been estimated that it would require four hundred million of them of average size, to cover one square inch of surface. In their multiplication, a single germ becomes the causative parent of thirty or forty million descendents in a day.

In an interesting investigation(29) at the city of Paris it was found that in a cubic mètre of air above ground there were ten thousand germs; in the sewers, thirty-six thousand; in old houses, forty thousand; and in the hospital of Petie, seventy thousand. And these organisms are absorbed by water exposed to the air.

Dr. Percy F. Frankland(30) has found that average river-water, like the Thames, contains about twenty thousand germs per cubic centimetre, and that this number is greatly reduced when the water is submitted to storage and filtration; but there is no reliable artificial method for their entire removal, except by the agency of heat.

*Bacteria* are almost universal in all kinds of matter. They inhabit the air we breathe and the food we eat, and even the purest water is never free from them. The harmless forms of *Bacteria* have their uses in the economy of nature. It is to them that we owe the phenomena of fermentation and decay, as they effect a transmutation in organic substances, and finally elaborate them nto organic products. By the united efforts of *Bacteria*, sugar is converted into alcohol, and the cork of the champagne bottle is discharged with explosive violence. While one class of *Bacteria* is thus engaged in making alcohol, another class is fermenting it into

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(29) Water, Moore, p. 7.

(30) Report of Maine State Board of Health, 1887, p. 316.

acetic acid; and other classes still are servants to the baker in raising his bread.

Each group of pathogenic *Bacteria* has its specific organ for attack. Thus the *Bacillus Tuberculosis* generally has its seat in the lungs; the *Typhoid Bacillus* penetrates the mucus membranes of the intestines and accumulates in the spleen; and the *Bacillus of Diphtheria* produces extensive layers of false membranes in the fauces. Each group has its own distinctive character; some seem to evolve higher types of life; some prey upon and seem to devour others; and they are quite probably the cause or the result of every zymotic disease.

In some instances, *Bacteria* are capable of being conveyed to great distances in water, without losing the vitality necessary to produce disease. Indeed, it is a very difficult matter to deprive some forms of *Bacteria* of their vitality; they may be frozen or even heated to the boiling point of water and yet many of them are not destroyed. They may be kept dried for years, and when placed in a favorable medium are yet capable of producing disease.

The noted outbreak of Typhoid Fever at Lausen, Switzerland, and at Plymouth, Pennsylvania, has shown that the dejections from a single Typhoid Fever patient are sufficient to poison the water supply of a whole town, and give rise to an extended outbreak of fever. It is, therefore, apparent that human fæcal matter is very dangerous, as it may contain germs capable of setting up a specific form of disease. As sewage is largely made up of this kind of matter, it is a very dangerous form of pollution. Sewer gases are also productive of disease, (31) especially when the atmosphere is heavy, as it then favors the accumulation of the products of decomposition and the production of germs. Wherever *Bacteria* are found abundantly, decomposing nitrogenous organic matter is always present; and Pasteur has shown that *Bacteria* do not multiply without a putrefactive environment, but remain infertile until they perish. These germs only flourish in a neutral or alkaline menstrum, such as is produced by decomposing sewage matter, when

(31) Report of Michigan State Board of Health, 1885, pp. 64-65.

aided by heat, and all standard authorities agree that these alkaline waters are dangerous for drinking purposes. Water which contains an excessive quantity of the alkaline carbonates tends to make the system alkaline, and physicians often find it necessary to put patients suffering with digestive, intestinal, and renal diseases, upon distilled water as a beverage, and with happy effects.

In the healthy human system germs do not thrive, as the reaction therein is acid. But in persons afflicted with digestive disorders, in which the gastric juice is restrained, pathogenic germs find a fertile soil and muliply with inconceivable rapidity. A free supply of gastric juice will kill and digest them. (32) A good corrective for alkaline polluted waters is sulphuric acid. This arrests putrefaction and destroys the germs. Workmen, whose employment, location and habits, favor an attack of zymotic disease, sometimes prevent an epidemic by drinking water acidified with one or two drops of sulphuric acid per pint of water. (33) Sulphuric acid is also often used with great advantage in treating cases of Cholera and Typhoid Fever, by giving ten to thirty drops of acid in water three times a day. Hydronaphthol is also recommended as a corrective for polluted water; it is a powerful germicide and is harmless to the human system. Pyridine, a constituent of tobacco smoke, is also a powerful destroyer of *Bacteria*. It is a fact worthy of notice that men who use tobacco are less susceptible to zymotic infection that those who do not use it, and that women are more frequently attacked with Diphtheria and Typhoid Fever than men.

In the production of contagious and infectious diseases, it appears that the organic matter throws the *Bacteria* into a state of excitement in which they seize upon the membranes of the body and develop the functional disturbance known as disease, and this disturbance is in proportion to the degree of pollution of the water; while in pure water the *Bacteria* remain in a latent condition. (34) Slightly

(32) The Sanitary Era, October 1, 1888, p. 76.

(33) Report of Examination of Water from the River Schuylkill, Cresson, pp. 13-14.

(34) Report of Connecticut State Board of Health, 1886, pp. 294-298; Reports of Kansas State Board of Health, 1886, pp. 228-235; and 1887, p. 303.

contaminated water often produces zymotic diseases in weakly persons, while persons of robust health may withstand its action. But it is impossible to banish disease from a town whose water supply has been even slightly contaminated with the dejections from fever patients, as the weakly inhabitants will contract the disease first, from the almost inappreciable amount of infection contained in the water, and from them the disease will spread to those who have resisted its action in a diluted condition.

## VI. WATER SUPPLIES.

*Rain-water.*—There is a popular idea that rain-water, as it falls, is perfectly free from impurities; but in fact, the first fall of rain after a drouth is swarming with living organisms, which multiply and perish, polluting the water with the products of their decomposition. Even the purest air contains myriads of motes which can be seen in the sunbeam with the naked eye, and they are washed from the air by the descending rain. The exhalations which rise from decomposing organic matter, and float in the atmosphere, are also carried down in the rain or even humid air, so the first rain that falls during a storm is always more or less impure, and unfit for drinking purposes; but the air becomes purified in a short time, and the rain that falls thereafter is approximately pure water.

The British Rivers Pollution Commissioners concluded that "half a pint of rain-water often condenses out of about three thousand three hundred and seventy-three cubic feet of air, and thus in drinking a tumbler of such water, impurities, which would only gain access to the lungs in about eight days, are swallowed at once."(35) These impurities consist of ammoniacal salts, nitrous and nitric acids, sodium chloride, calcium compounds, and organic matter; and the solid impurities usually amount to two or three grains per gallon. And when the water has drained from the roofs of buildings, after a dry season, the additional impurities consist of dust, dead insects, excreta of birds, and probably dried disease germs. As the rain falls, it becomes thoroughly aerated; but rain-water has usually a

(35) Potable Water, Ekin. p. 9.

flat, smoky taste, caused by the absence of carbonic anhydride and alkaline salts.

In some of the southern cities,[36] near the Gulf of Mexico, where it is impossible to secure a supply of pure well or spring-water, rain-water is used extensively for domestic purposes. It is very important in the construction of cisterns for storage of drinking water that great care should be exercised in preparing the walls against any leakage from cess-pools and privies. Rain-water, when collected toward the end of storms and properly filtered through sand and charcoal, is perfectly wholesome, provided there is no drainage into the cistern.

*Well-water.*—The purity of well-water depends mainly upon the depth and situation of the well, and the nature of the surrounding soil. Deep wells, when properly made, are generally free from organic impurities, but their waters are impregnated with hardening salts. Artesian well-water is also free from organic impurities, but it is usually highly mineralized. Deep well-waters are not best suited to the digestive powers of man; and every intelligent groom and herdsman knows that such waters are also more prejudicial to horses and cattle than even the water of a muddy stream.

The abundance of filth in densely populated cities renders the soil unfit for the filtration and storage of water, and surface wells in such soil furnish only a polluted and dangerous supply, as the water is not sufficiently aerated for the oxidation of its organic matter. These wells are frequently situated in too close proximity to dwellings, stables, cess-pools, privy-vaults, and other sources of pollution, and they are thus frequently important factors in disseminating disease.

Rain-water, as it passes into the earth, extracts from the surface soil great quantities of impurities, like decaying vegetation and the filth and excrement of animals, which it carries down into the circulating currents, and it often happens that the drainage of cess-pools and privies finds a direct channel into the well. The germs from diseased patients thus find their way to the water supply, and

(36) Report of Connecticut State Board of Health, 1885, pp. 254-255.

many surface wells are nothing more than receptacles for diluted excrementitious matter.

It is said that the circulation of water is so thorough in the earth that if a barrel of kerosene oil be placed ten feet under ground, every well within a quarter of a mile will be contaminated, and the oil will be apparent to the taste.(37) It has been demonstrated that in compact soils, the level of the ground water is influenced by pumping, for a distance of two hundred feet in all directions around a well, while in loose, gravelly soils, the circle of influence may have a radius of more than two thousand feet.(38) This produces a circulation of water toward the center, and consequently a washing of the filth of the soil into the well. No stable, cess-pool, privy-vault, or other source of contamination should be within this radius.

Many severe outbreaks of epidemic diseases have been traced to the use of surface well-water in cities, and there is strong reason to believe that sporadic attacks of Typhoid Fever often occur in isolated country homes from the same cause. When scientific views concerning the pollution of well-waters are disseminated, surface wells will be rapidly abandoned by the intelligent classes.

In the ordinary method of bricking or walling a well, no protection is offered against surface drainage, and a deep well thus constructed is no better than a surface well. Open wells should always be walled with hydraulic cement above the water line, to prevent the admission of filth. Surface contamination is also prevented by the use of deep "drive-wells;" with these the only pollution comes from the downward circulating currents. Wooden curbing for wells is a serious source of danger, as the wood soon becomes rotten, contaminates the water, and promotes the growth of fungi.

*Spring-water.*—Springs are fountains of water which flow from subterranean channels. This term is sometimes incorrectly applied to mere shallow pits, filled with water oozing from marshy surroundings, and with little or no visible outflow. The water which gathers into the subterranean channels descends from the earth's surface; and if the surface water is polluted, the springs which

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(37) Water, Moore, p. 31.
(38) Water Supply, Nichols, pp. 109-114.

receive their supplies from it are liable to be impure. The organic constituents, in filtering through the earth, oxidize to harmless inorganic products, if the filtering bed is sufficiently deep; but disease germs are not thus destroyed.

Spring-water which flows from hill or mountain sides is generally cold, and has a uniform temperature the year around. Springs are also superior to wells on account of their freedom from the accumulated matter which is always found on the surface of well-waters.

Average porous soil contains about two hundred and fifty times as much carbonic anhydride as does air, and this is taken into the percolating water as it filters into the subterranean channels, and it renders the water especially palatable. It is this carbonic anhydride in water which dissolves limestone, converting it into soluble bicarbonates.

It is, therefore, evident that springs furnish us the best water, as they are generally free from organic pollution, and their waters are very palatable from the gases held in solution. "A perfectly pure spring-water is certainly the most healthy beverage in the world. Such waters are abundant, and can now be easily obtained. It will be a happy day for us all when their use shall have become general or universal for drinking purposes."(39)

*River and Lake-water.*—Rivers are the natural drains of the territory through which they flow, being fed by smaller streams, springs, rains and surface drainage. "They are the receptacles of all the waste products of the inhabitants of the district; they receive the contents of sewers, cess-pools and privies; the offal of distilleries, slaughter-houses and tanneries, and the refuse of factories. Into them are thrown carcasses of dead animals, as the most expeditious method of burial. From swamps they receive the matter of vegetable decomposition, and are discolored by flowing over beds of peat."(40) The factories that are especially objectionable are dye works, sugar refineries, starch works, and glucose works. Rivers are also sometimes polluted by the filth from stock yards.

The Prussian government protects its public water supplies by

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(39) Hand-book for Water Drinkers, Austin, p. 13.
(40) Water Supply, Dickinson, p. 5.

forbidding the discharge of sewage into its rivers. Many of the organic substances which are washed into rivers from cities situated on their banks, undergo decomposition, and give rise to products, some of which have the power to produce disturbances in the human system, and others to propagate the germs of disease.

River-water, below the discharge of city sewage, is a filthy and dangerous beverage, and notwithstanding its natural purification by sunlight, by oxidation and by living organisms, it may never become free from disease germs. A stream which has received much filth in its course, should be considered objectionable for domestic use, unless the volume-ratio of the filth to the water is inappreciably small. The pollution of streams in rural districts, from the decay of vegetation, is always greatest in the Fall, and that from suspended matter, is always greatest in the Spring.

River-water originating in mountainous districts is unquestionably the best for city supplies, as under ordinary conditions it is softer than well or spring-water, and it is freer from organic and living matter than surface wells and stagnant lakes and ponds. The objections that are offered against the use of river-water are on account of its high temperature, frequent turbidity, and its liability to contamination; and it is true that some rivers furnish water only fit for hydrant and manufacturing purposes. But by the use of ice, efficient systems of purification, and proper precautions against pollution, river-waters are generally excellent supplies for cities and towns, where an abundance of pure water is needed. In the deep-well system for the purification of water, the wells receive only a part of their water from the river, on whose bank they are situated, as the ground-water is constantly flowing toward the river channel.

Lakes are the reservoirs into which rivers and other streams empty, and their waters are not widely different from their sources of supply. These great bodies of water remain cold during Summer, and they become somewhat purer by the sedimentation of their suspended matter. Pond-water often becomes unfit for domestic use, from the growth of *Algæ* and fresh water *Sponges*.

## VII. NATURAL PURIFICATION.

Streams are partially purified by the sedimentation of their suspended matter(41) which takes place as the velocity of the current diminishes. A stream which is very turbid after a heavy rain may soon become clear, owing to its diminishing velocity, and the insoluble matter either sinks to the bottom or is precipitated along the banks. The retarding influence of tidal waves also assists in the precipitation of suspended matter; and Barus(42) has shown that the sedimentation of fine particles is promoted by the action of salt water, so there is a rapid precipitation of silt where rivers enter the sea. As the mineral matter subsides, it generally carries down with it much of the flocculent, organic matter that would otherwise remain in suspension for many days.

An apparent purification of polluted water is effected by dilution, and the self-purification of many streams is largely due to this cause. Some of the chemical waste products of factories, when poured into rivers in large quantities, are sufficient to render the water wholly unfit for domestic use, but in the course of a few miles the pollution becomes so much diluted that the water is rendered harmless. In some cases, however, these products furnish a rank growth of *Algæ*, and the water is thereby rendered so objectionable that even fish cannot survive in it. This is the case with the Iowa River pollution.(43)

The mineral impurities of streams are sometimes removed by mingling their waters with other streams of a different nature, or by flowing over rocks which act chemically upon them. This is beautifully illustrated in the purification of the Schuylkill River before it reaches Philadelphia.(44) This river receives the drainage from many mines, and is in its upper course highly charged

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(41) "The water of the Mississippi contains forty grains of mud per gallon; and it is estimated that this river carries four hundred million tons of sediment per annum into the Gulf of Mexico. The Ganges is said to carry down six billion, three hundred and sixty-eight million cubic feet annually."—[Report of American Public Health Association, Vol. I, p. 536.]

(42) Bulletin, No. 36, United States Geological Survey.

(43) Monthly Bulletin, Iowa State Board of Health, July, 1889.

(44) Examination of Water for Sanitary and Technical Purposes, Leffmann and Beam, pp. 10-11.

with iron salts and free mineral acids, and its water is unfit for domestic and manufacturing purposes. In its course, the river passes through an extensive limestone district, and into it are emptied several large streams, highly charged with calcium bicarbonate. The free acids are thus completely neutralized, and the iron and much of the calcium are precipitated. At Philadelphia the water is soft and superior to the water at the source of the river or at the middle Schuylkill region, as it contains only traces of iron and a small amount of calcium sulphate.

Running water, especially when it flows over cataracts or is thoroughly agitated in the air, absorbs oxygen to such an extent that its organic matter becomes rapidly oxidized; and the purification of water is also greatly promoted by the agency of sunlight. This is one of nature's most efficient methods of self-purification, and "the pure water of mountain streams and swiftly-running brooks and rivers owe their freedom from organic impurities largely to their continued and violent contact and admixture with atmospheric air."([45]) Some organic substances easily oxidize into ammonia, nitrites, nitrates, and carbonic anhydride, while others, like muscular fibre, may remain for months in water, and still be recognizable under the microscope. These chemical changes take place most rapidly in Summer, owing to the favorable conditions of heat, light and motion; but in Winter the oxidation is retarded by the low temperature and the ice formations which shut out the light and air and impede the motion of the water.

The pollution of English streams is carried to such an enormous extent that the waters of many, where city sewage enters them, are actually offensive. In their course, the water and banks become blackened from the formation of sulphide of iron, and with this formation the Sewage Fungus appears. Further on in their course, the black color of the water and the Fungus decrease and disappear, and in their place vegetation is luxuriant, fish abound, and the water becomes clear and apparently pure, from its dilution and oxidation, and from the agency of vegetable and animal life. The

([45]) Water Supply of U. S. Capitol, 49th Congress, 1st Session, Ex. Doc. No. 154, p. 20.

distance which running water requires for its apparent purification, depends mainly upon the extent and nature of its pollution, the inflowing streams, and the agitation of the water in its course, and it is safe to say that it generally requires from five to twenty miles. ([46])

But self-purification is no guarantee that running water is perfectly wholesome at *any* distance below a point where it was certainly polluted with the contents of sewers and privy-vaults, or the products of decomposition of vegetable and animal matter. The question, to what extent must impure water be diluted or oxidized to render it safe for domestic purposes, cannot be answered. Mere dilution of polluted water does not render inoperative the action of living *Bacteria*, owing to the marvelous rapidity of their reproduction; and under favorable conditions, it requires only a few days for pathogenic *Bacteria* to render water exceedingly dangerous, even though in other respects it is comparatively pure.

In freezing, water is partially purified, ([47]) as this operation eliminates a large portion of its suspended matter, but the inorganic salts, and the organic constituents, are only partially removed. The experiments of Dr. C. P. Pengra([48]) show that water in freezing is only freed of about fifty per cent of its organic crystalloids, twenty per cent of its colloids, forty per cent of its mineral salts, and ninety per cent of its *Bacteria*. It is, therefore, evident that ice may be a prolific source of disease, and many dangerous epidemics([49]) have been caused by it. The impurities excluded in freezing remain in the unfrozen water, in a concentrated and more dangerous form, and this may in part explain why Typhoid Fever so often prevails, and is of such a severe type, during cold Winter weather.

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(46) Report of Massachusetts State Board of Health, Vol. VII, p. 146.*

*The Royal Commissioners concluded, however, that running water is so slowly purified that there is not a river in England sufficiently long to dispose of a moderate amount of sewage, through natural agencies.

(47) On Bacteria in Ice and Their Relations to Disease, Prudden; Our Ice Supply and its Dangers, Prudden.

(48) Reports of Michigan State Board of Health, 1882, pp. 48–50; and 1884, pp. 79–81.

(49) Report of Massachusetts State Board of Health, Vol. VII, p. 465; Report of Connecticut State Board of Health, Vol. II, p. 90.

The soil may act as a mechanical purifier of water, by the removal of suspended matter as the water filters through it, and as a chemical purifier, by its oxidizing and other chemical action upon the organic impurities, whether they are held in suspension or solution. The filtering power of soil is found to vary greatly.[50] Sand and gravel act mainly as mechanical filters, while ferric oxide is the oxygen carrier of the soil. In general, a coarse soil is not so efficient in its mechanical and chemical action as a similar finer one; and every soil which has been charged with organic inpurities is unquestionably inefficient. Even a good filtering soil which receives an excess of impurities, becomes, at last, ineffective.

Too much confidence, however, is often ignorantly placed in the purifying power of the soil. From experiments instituted by the National Board of Health,[51] it appears that sand and gravel interpose absolutely no barrier between wells and the *Bacteria* of cesspools, privy-vaults, and cemeteries, lying even at great distances from them. In further support of this view, one celebrated case will suffice: In August, 1872, an outbreak of Typhoid Fever occurred at Lausen, near Basil, in Switzerland.[52] The village water supply was from a spring at the foot of the Stockhalden. Suspicion was attached to this water, for it was found that the six houses using well-water were free from the disease, but scarcely one of the others escaped. Upon investigation it was found that Typhoid Fever had occurred at a farm-house on the opposite side of the Stockhalden, and the drainage from this house went into a brook, a part of which was lost in the mountain, about a mile distant from Lausen. Large quantities of salt were thrown into the stream and the salt was soon detected in the Lausen supply, thus proving the connection between the two. Several hundred pounds of flour were then thrown into the stream, but not a trace of it was detected in the water supply, showing the thorough filtration of the water in passing through the mountain. The case was elaborately investigated by Dr. A. Hagler, of Basil, and it is of the greatest

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(50) Report of Michigan State Board of Health, 1876, pp. 110-111.

(51) Report of National Board of Health, 1882, p. 582.

(52) Nature, Vol. XIII, p. 447.

interest in showing that the most thorough filtration through soil is insufficient to remove Typhoid Fever germs from polluted water.

Finally, we are indebted to low forms of life for much of the self-purification of water. The decomposition of organic matter is the joint work of a number of independent organisms, the results of one class following those of another until organization is entirely destroyed.

The *Entomostraca* and other low forms of animal life, owing to their fecundity, are very important factors in removing organic impurities from water. Some of them seem to act mostly as catalytic agents, producing chemical changes by which the noxious organic constituents are converted into harmless products.

Notwithstanding what has been said concerning decomposing *Algæ*, the living forms of *Algæ* should not be considered an unmitigated evil, as most of them are really purifying agents, since they assimilate the dissolved organic matter in water. They also assimilate the carbonic anhydride, ammonia, and nitrogen acids produced by lower forms of cryptogamic life. The main function of *Fungi* in the purification of water is apparently the oxidation of organic carbon.(53) Next of importance is the great army of *Bacteria*, which embraces many families of similar physical structure, but the families are endowed with very different chemical powers. They sweeten water by a chemical process necessary for their own nutrition; and our water supplies would become magazines of deadly poisons, were it not for the myriads of these micro-organisms which attack dead organic matter, and cause its elements to enter into new and useful combinations. One class of *Bacteria* converts the nitrogen in nitrogenous organic matter into ammonia; another class elaborates this ammonia into nitrous and nitric acids; while another class is engaged in converting organic carbon into carbonic anhydride. Experiments(54) show that sterilization of polluted water arrests the decomposition of its organic matter, for ozone and hydrogen peroxide fail to oxidize it; but when such water is subjected to biological agencies, it is purified as usual. Indeed, it

(53) Report on the Waters of the Hudson River, Chandler, January, 1885, pp. 7–14.
(54) Report of Kansas State Board of Health, 1887, pp. 328–329.

appears that the removal of organic impurities is more of a biological than of a chemical question, and in considering the natural purification of water, the action of micro-organisms should have the first rank, even though some of them are pathogenic.

It is well known that these chemical changes are more rapidly effected when the water filters through the pores of the soil, than when it is stagnant, or even when it is flowing in the current of a stream. This is explained by the fact that the purifying *Bacteria* mainly have their abode in the three or four feet [55] of surface soil of the earth, and that they so modify the organic matter of water as it passes through this layer of soil, that the roots of living plants can absorb and assimilate it.

## VIII. ARTIFICIAL PURIFICATION.

*Processes.*—Water may be artificially purified by any of the following processes: Boiling, distillation, aeration, sedimentation, precipitation and filtration.

*Boiling.*—By boiling polluted water for some time, the living organisms in it are always partially, and generally entirely destroyed. *Algæ* and *Fungi* are easily killed in this way. Professor Tyndall [56] has shown that there are periods in the life of *Bacteria* when they can resist the action of boiling water; but as they soften before propagation, water containing them, can be completely sterilized by repeated boiling, for at the proper time, this not only destroys the *Bacteria* but it destroys their spores as well. In order, then, to guard ourselves against these organisms, polluted water should never be used for drinking purposes, without first being boiled for some time (two or three hours), as this prolonged operation thoroughly sterilizes it. Indeed, it is perhaps true that the two most effective measures which can be taken in avoiding zymotic diseases, consist in boiling all the water and milk that we use for drinking purposes.

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(55) Report of Committee on the Pollution of Water Supplies, American Public Health Association, 1888, p. 11.

(56) Practical Hygiene, Parkes. Seventh Edition, p. 79.

*Distillation.*—Water may be freed from its solid impurities by a process of distillation. In this way, inland bodies of water and the seas, become saline from the concentration of their mineral constituents, while water in its crystalline purity evaporates from the surface. In the first part of distillation, the occluded gases are liberated, and they pass over with the distillate. It has also been claimed that *Bacteria* and their spores are carried over with the distillate, but the evidence is very unreliable. The flatness of distilled water, which is always objectionable at first, is said to be preferred by some people who have accustomed themselves to it; but this objection can be partially overcome by aeration. Distilled water is not generally used for drinking purposes, except by persons afflicted with renal and bladder difficulties. But it is said to be used regularly on the coast of Chili,(57) where it is made from sea water, and it is used oftentimes on long ocean voyages and expeditions, where fresh water cannot be obtained. As coal will distill about eight times its weight of water, there is an advantage in conveying coal instead of fresh water on board of ships.

*Aeration.*—Artificial aeration is a process by which we imitate nature in the purification of water. This oxidizes organic matter to harmless products, and renders the water highly palatable. As a process, aeration was introduced by Lind more than a century ago, for the purification of water on the western coast of Africa. This process has since been used on a large scale in Russia, by allowing the water to flow down a series of steps, passing through wire gauze as it descends, and it has also been used on a small scale in Paris. But artificial aeration has only recently been introduced in this country for city water supplies. In 1883,(58) Professor Albert R. Leeds demonstrated by laboratory experiments, that the temporary offensive contamination of the Schuylkill water at Philadelphia, could be removed by oxidation, and at his suggestion the Philadelphia Water Company removed the objection by pumping air under great pressure into its supply. At a subsequent date, the water supply of Hoboken, New Jersey, became extraordinarily

(57) Water Analysis, Wanklyn and Chapman, Sixth Edition, p. 107.

(58) Water, Moore, pp. 72–74.

offensive in odor and taste, and an examination by Dr. Leeds showed this water also to be deficient in oxygen. In September, 1886, the evil was removed by artificial aeration, and the impurities were diminished and vegetable growth ceased.

The water of the Greenwood Cemetery Water Works, Brooklyn, New York, some time since became nauseous from the accumulation of a greenish, vegetable slime. Examination revealed the fact that the water was deficient in dissolved oxygen, and that it contained an unusual number of *Diatoms*. The problem was, therefore, to devise a process which would remove the pabulum necessary for their growth. An amount of air equal to one tenth of the water, under a pressure of eighty pounds per square inch, was found sufficient to oxidize the pabulum, and the water was rendered clear and sparkling by this artificial aeration.

Under great pressure, air oxidizes nitrogenous substances to inorganic products, and it therefore deprives the minute forms of life of the pabulum on which they thrive, and they are rendered latent. But it must not be understood that mere aeration effects these transformations, for experiments[59] have clearly demonstrated that without the aid of biological agencies, there is no oxidation, and no purification from the aeration of water. Oxidation is, indeed, but a finishing process, and, therefore, after coagulating and filtering out the bulk of impurities, a vigorous aeration, under high pressure, in such a manner as to cause the oxygen to reach every portion of the water should be effected, and the oxidation there completed so far as possible. The excessive air should then pass to the filtering beds, and in its slow passage through them assist in the separation and removal of the organic impurities. From such a system water would emerge from the pipes highly charged with air, clear, sparkling, and as wholesome as the best standard of nature's purified springs.

*Sedimentation.*—In this country, the water for city supplies is often only partially purified by a process of sedimentation. This process is frequently used for the waters of the Mississippi and

(59) Report of Kansas State Board of Health, 1887, pp. 328–329.

Missouri Rivers. The water is allowed to remain at rest for some hours, in large, shallow settling basins, in which much of the suspended inorganic matter subsides, and thus mechanically removes much of its organic matter; but owing to the expense of constructing, maintaining and operating settling basins, their use is not more extended. Other systems of greater sanitary merit do the work of purification more beautifully and to the satisfaction and delight of the water consumers. After subsidence of the impurities, the water is drawn off, and at regular intervals the sediment is removed from the basins. If the water contains finely divided particles of clay, then the subsidence is so slow that for purifying purposes this process is a failure, and the softer the water the more slowly the sedimentation. It is said that the fine argillaceous matter in the River Rhone requires four months of undisturbed repose for its subsidence. Time is, therefore, an important element in the purification of water by this process.

If the water is contaminated with sewage, or with the decomposition products of vegetable and animal matter, the sooner it is used the less harm it will generally do. "To detain it in a settling basin, especially in Summer, long enough for even its suspended mineral matter to go to the bottom, is to brew a sort of devil's broth out of the putrescent ingredients, that will grow more poisonous every day it is kept."(60) As the growth of micro-organisms is prevented or at least retarded by the absence of sunlight, it has been found advantageous to store water, after sedimentation and filtration, in covered reservoirs. Dr. Percy F. Frankland(61) has found that the twenty thousand germs per cubic centimetre in the Thames River water are reduced to about four hundred by subjecting the water to sedimentation and filtration; but from ninety-five and five tenths to ninety-eight and nine tenths per cent of the micro-organisms in the London water supply are claimed to be removed by filtration alone.(62)

(60) Water, Moore, p. 72.

(61) Report of Maine State Board of Health, 1887, p. 316.

(62) Report on Water Supply of East Saginaw, Michigan, p. 4.

*Precipitation.*—Many substances have been found useful in precipitating the impurities from water. Among those that have been mentioned are carbon, borax, ferric chloride, potassium permanganate, alum, calcium hydrate, and sodium carbonate. The choice of a substance depends upon the nature of the impurities, the use of the water, and the magnitude and expense of the purifying system. A few points concerning some of these substances will suffice.

Ferric chloride(63) to the amount of two and one half or three grains per gallon of water has been used successfully in Holland in removing argillaceous and finely divided organic matter from water. It is a powerful oxidizing agent, and when followed by a solution of sodium carbonate, it gives excellent results, as the carbonate precipitates the iron, which entangles and removes the organic matter.

Potassium permanganate (in solution as Condy's red fluid) is an excellent purifying agent, as it partially destroys organic substances by oxidation, and its manganese is generally precipitated as the binoxide, carrying with it much of the suspended matter present. A yellowish tint is sometimes produced in the water by the finely divided particles of oxide of manganese, and although this may be objectionable to the sense of sight, it has perhaps no ill-effects upon the human system. This reagent readily removes any offensive odor from water, but the degree of oxidation of the organic matter depends somewhat upon the structure of the organic matter and the temperature of the water. Potassium permanganate is not a complete purifier of water, but it does work which alum cannot do.

Alum has been used for centuries in China and India to purify water. It is especially efficient with waters containing calcium bicarbonate, and it clarifies them by precipitating the calcareous and argillaceous impurities, and in their removal it is itself precipitated as calcium sulphate and aluminium hydrate, which coagulate and remove the albuminous matter. So perfect is its self-precipitation that rarely can we find a trace of alum in the filtered water.

(63) Water, Moore, p. 76.

Professor Leeds has shown that alum has also the remarkable property of removing *Bacteria* from water. This is the coagulent used in the Hyatt system of purification. The amount of alum used is from one half to six grains per gallon of water. Alum can be obtained for one and one half to two cents per pound; so its use under the most unfavorable circumstances is very inexpensive.

Clark's process for softening water by precipitating its lime as a normal carbonate, has been successfully used in several European water supplies, and also for private consumers. This is accomplished by adding to the water in settling basins a sufficient quantity of calcium hydrate, in solution, to completely neutralize the carbonic acid, and thus precipitate all the lime as a normal carbonate. This carbonate mechanically precipitates the clayey substances, and effects a nearly complete removal of the coagulated, gelatinous and albuminous matter, as well as a complete removal of the coloring matter. Professor Edward Frankland has shown that Clark's process is very efficient in removing living organisms from water. The completion of the removal of lime is determined by means of a solution of silver nitrate. So long as the bicarbonates remain in solution the silver nitrate gives a white precipitate with the water; but as soon as the bicarbonates are removed, then a brownish or yellowish precipitate is formed. The objections offered against this system are that if organic matter is present in large quantity the chalk will not readily precipitate; the expense of constructing settling basins is very great; and the accumulated chalk needs frequent removal from the basins, and consequently entails much expense. A modern improvement in this process, known as the Porter-Clark process, consists in a remarkably rapid separation of the precipitate by means of a filter-press, which obviates the difficulty of sedimentation, and dispenses with the expensive settling basins.

Sodium carbonate, or salsoda, is frequently used in softening water for laundry purposes, as it precipitates the hardening salts as normal carbonates.

*Filtration.*—The purification of water by filtration for city supplies has become quite general in Europe and most parts of the

United States. The essential object attained in this method, when the water is to be used for domestic purposes, is the removal of the pabulum or infectious matter, on which disease germs multiply and develop. Experience shows that this is best effected by first coagulating and filtering out the organic matter, in part, and then complete its removal by rapid oxidation under high pressure. A large per cent of the *Bacteria* are thus removed in filtering, and the remaining few are rendered latent, and the water becomes harmless and palatable.

A filter should not only be capable of arresting suspended matter, but also all substances in solution which are physically or chemically dangerous, and it should so retain them that the water cannot wash them out again. It should also be so constructed that it can be used for some time without deteriorating the quality of the water.

Filtration effects purification in three distinct ways:

1. By straining, in which the efficiency and rapidity of the operation depends upon the size of the pores.

2. By adhesion of the impurities to the filtering substances, in which the efficiency depends upon the nature of the filters, and the relative surface of the filter pores to the water filtered.

3. By sedimentation within the pores of the filter, and the efficiency here depends upon the size of the porous cavities and the rate of filtration.

Professor Edward Frankland, of the Royal Commission, has thoroughly investigated the efficiency of the various methods of purifying water, and the following are the results of his observations upon filtration:(64)

1. A proper filtration may entirely deprive water of its living organisms.

2. By storing water in receptacles which are biologically unclean, living organisms may be introduced and rapidly multiplied.

3. Filters lose their efficiency by constant use, and instead of removing *Bacteria*, they finally increase the number of these organisms.

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(64) Journal of the Society of Chemical Industry, December, 1885.

4. Some substances which manifest no chemical action on water, are very successful agents in removing living organisms from it. Such are charcoal and coke.

5. The best results are attained when the filtering substances are frequently removed.

6. What is gained in the rapidity of filtration is lost in its efficiency.

Sand is the material most frequently used in filtering-beds, although, compressed sponge, animal and wood charcoal, coke, brick, porous tiles, unglazed earthenware, sandstone,[65] carbide of iron, and spongy iron have been suggested.

Animal and wood charcoal, coke and spongy iron are the only substances which can be relied upon for the removal and destruction of organic matter. Charcoal condenses oxygen in its pores, and as water passes through it the organic matter is rapidly and powerfully oxidized, the charcoal acting as a catalytic agent. But it is necessary that charcoal filters be frequently removed and exposed to the air, or sometimes reburnt, that they may become purified and absorb a fresh supply oxygen, for a filter that is kept constantly in use soon become worthless.

Dr. Percy F. Frankland has found that powdered coke as a filtering material completely removes micro-organisms from water; and Salamon and Matthews[66] have further shown that the action of the coke is due mainly, if not entirely, to the presence of iron.

In constructing filters for cisterns, care should be taken to so arrange the parts of the filter that all organic matter possible may be removed, and that no color may appear in the water. For this purpose the conducting pipe from the roof should lead directly to the filtering box, in which there should be layers of charcoal, gravel, and sand of such a thickness as to effect this purification. The water should only flow into cisterns during the Winter and Spring months, when the atmosphere is clear and the rain pure.

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(65) "The Japanese use porous sandstone hollowed into the form of an egg, and set in a frame over a vessel, into which the water drops as it percolates through the stone. The Egyptians adopt the same method for clarifying the water of the Nile."—[American Cyclopædia, Second Edition, Revised, p. 189.]

(66) Journal of the Society of Chemical Industry, 1885, p. 261.

The filters should be cleansed at least once a year. Under proper management a supply of pure, cold, cistern water may always be at hand. Cisterns are sometimes constructed in two vertical compartments, separated from each other by a porous brick partition, laid in hydraulic mortar. The water is allowed to flow directly into one of the compartments, and filter through the brick wall into the other, from which it is drawn for use. At first, this is a very successful means of filteration, but the partition soon becomes charged with impurities, and finally does more for contamination than for purification.

Any filtering medium, like sand, and uncompressed charcoal and coke, which has pores larger than one twenty-five thousandth of an inch in diameter, cannot successfully mechanically remove *Bacteria* from water. But Pasteur has devised a sanitary filter which eminent authorities claim is germ-proof. The filtering material in this is a fine porcelain imported from France. These filters, which are only suitable for domestic purposes, consist of two concentric tubes, the outer one being connected with the water pipe, and the inner tube is the porcelain filter. The water is admitted to the anular space between the two tubes, and it filters through into the central space, from which the clear, sparkling water is drawn. These filters are so constructed that they can be easily and daily cleansed. Other forms of sterilizing filters are in use, but the writer is not prepared to attest to their efficiency.

*Systems for central filtration.*—One of the simplest and cheapest methods[67] of securing filtered water for city supplies is to sink wells or pits to a depth of ten to forty feet into the soil, near the bed of a river or lake, and from them pump the water for general distribution. These wells are inclosed with iron or masonry walls, which prevent an influx of surface soil-water. The river or lake water only enters them at the bottom, and it is thus subjected to filtration through natural soil. These wells generally receive a portion of their supply from the ground-water, and if this flows from underneath a densely-populated city it is liable to be impure. But this system gives satisfactory results when the wells are sunk

(67) Water Supply, Dickinson, pp. 10–11.

below an impervious stratum, for this separates the surface water of the city from the influx to the well.

In the Filter-bed system(68) the basins, as usually constructed, are from ten to sixteen feet in depth. Their size varies from twenty thousand to one hundred and fifty thousand square feet, and is determined by estimating that ninety gallons of water can be filtered per day through each square foot of surface. These basins are made water-tight by masonry, concrete or puddled clay walls. In the bottom are radiating drains, upon which is a layer of broken stone some two feet in thickness; then layers of coarse gravel, fine gravel, and finally the true filter, which is a layer of fine sand, from one to four feet in thickness. The water is kept from one to four feet in depth above the filters, and it is purified in its downward passage through the sand, and flows through the drains to a clear-water basin. When the filters become clogged the water is drawn below the surface of the sand, and a layer of sand from one half to three fourths of an inch in thickness is removed, together with the debris which has accumulated on its surface. This practice is continued until the sand becomes too thin for efficient filtration, and then a new filtering-bed is prepared. This system is especially applicable to the purification of river-water, but the sand only acts as a mechanical strainer.

In the Bishof system the sand of the filtering bed is mixed with a prepared spongy iron, which is said to successfully remove organic matter from the water, and thus render it wholesome. If the water contains a large amount of fine sand, a preparatory filtration is necessary, and if there is also a large amount of salts in solution, then the water is liable to be impregnated with salts of iron derived from the filtering-bed.

The Anderson system, so successfully used in purifying the Antwerp water supply, consists in passing the water slowly through revolving iron cylinders, having inside projecting shelves. These cylinders are about two thirds filled with iron borings, and are slowly revolved, so that some of the iron passs into solution as

(68) Water Supply of U. S. Capitol, 49th Congress, Ex. Doc. No. 154, pp. 13-15.

ferrous hydroxide. Every particle of the water passing through the cylinder is thus brought into direct contact with the iron, and the ferrous hydroxide successfully removes the odor from the water and precipitates the organic matter, which is removed by filtering through sand, and in filtering, the ferrous salt is oxidized and removed. Professor Edward Frankland has shown that prolonged agitation with solid particles in the water completely destroys the living organisms; but the Anderson process, at Antwerp, only partially sterilizes the water. The quantity of nitrogen is reduced to one half or one third the amount which the water originally furnished. At Antwerp, the time required for the water to pass through the cylinder is about three and one half minutes, and for the completion of the purification, about six hours.

The Tweeddale system,(69) devised by Col. William Tweeddale, of Topeka, Kansas, has proved very efficient on a small scale, and gives promise of great satisfaction for the purification of city water supplies. The lime is precipitated as in the Clark process; then a sufficient quantity of carbonate of iron is added to render insoluble the organic matter. If the water is hard and clear, a small quantity of clay is then added. The water is then violently agitated by means of an air injector, after which the water is allowed to stand for ten minutes to complete the reaction. The water is again violently agitated from fifteen to twenty-five minutes, after which the impurities are allowed to settle, and the water is removed by decantation. The impurities must be frequently removed from the tanks. The time required for the clarification by this process, is from three to four hours. In this system the water is softened, the organic matter is largely precipitated and the balance oxidized to inorganic salts, while the living organisms are mostly destroyed.

In the Hyatt system of purification, the inconvenience and difficulty attending the frequent removal of sediment and sand in the previous methods, are obviated. In this system the filters can be easily, cheaply and thoroughly cleansed. The impurities are coagulated by means of alum, and the water then passes to the steel filtering chamber where they are removed. This is a vertical cylinder,

(69) Report of Kansas State Board of Health, 1887, pp. 330-331.

having a diameter nearly twice its height. Through the middle is a horizontal diaphragm capable of withstanding the hydrostatic pressure necessary for rapid filtration. The lower section of the cylinder is filled with the filtering material, which consists of two parts of coke and three parts of sand. The upper part of the cylinder is used for washing the filtering material, which is transferred to it at regular intervals in a state of violent agitation by hydraulic currents, and the impurities flow away through pipes situated near the surface. The water is admitted through pipes to the upper part of the lower section of the cylinder, and it is drawn out through perforated cups which admit the water but exclude the sand. The efficiency of this system depends more upon the successful precipitation and entanglement of germ life by the coagulent than upon the merits of the filter. Aerating systems are also attached to large plants, and are said to give excellent results. The Hyatt system is not only one of the most perfect for central purification, but it is also successfully used for private supplies.